TNO Defence, Security and Safety

Kampweg 5
P.O. Box 23
3769 ZG Soesterberg
Nederland

www.tno.nl

T +31 346 356 211
F +31 346 353 977
info@tm.tno.nl

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Summary

Purpose
Soldiers who need to navigate using a visual display do not have their eyes and hands available for other tasks. This can be prevented by presenting navigation information on a tactile waist belt, which proved to be effective in a previous study. In the current study, soldiers' performance on navigation and target detection in night operation was compared for three different systems: the tactile navigation system (called the Personal Tactile Navigator or PTN), the Land Warrior System (LWS) and a visual GPS system (PLGR).

Methods
Twenty-four enlisted U.S. infantry soldiers evaluated a tactile land navigation system in densely forested terrain. Each soldier also navigated equivalent 1500-meter routes with a Land Warrior System and a visual Army GPS system.

Results
System evaluation data reveal that the tactile system was rated positively by the soldiers. In all cases, the PTN system was rated higher than the visual GPS system, and in most cases the PTN system was rated as high as, or higher than the LWS system. Soldiers particularly appreciated the tactile system for its ease of use and enabling of eyes-free and hands-free navigation. However, the questionnaire data as well as soldier comments reveal that the PTN system is not appropriate for obtaining global Situation Awareness.

Conclusions
These results support the proven effectiveness of PTN for land navigation, also in adverse (visual) circumstances with a target detection task added. A potential stronger application could lie in combining the tactile and visual information, especially to provide improved global Situation Awareness. The potential advantages of a combined system, in which the soldier will rely upon tactile information for navigation, and occasionally check a visual display to obtain global Situational Awareness, will be tested in a follow-up study.

Contents

1 Introduction

Navigation by dismounted soldiers has been identified as having high potential for high workload and stress (Mitchell et al., 2004). Soldiers must navigate in terrain that is unfamiliar and often difficult to manoeuvre. During land navigation, the soldiers have to maintain situation awareness, may communicate verbally (by radio) and are engaged in other tasks such as enemy detection and obstacle avoidance. The level of multitasking during land navigation will vary in accordance to the task demands in a particular mission. Many of these mission aspects (navigating, situation awareness, enemy detection, etcetera) rely on visual information processing. In addition, navigation devices also usually rely on visual attention (e.g., compass, Global Positioning System (GPS) device). According to Wickens' Multiple Resource Theory (MRT; Wickens, 1984) this competition for the same modality can produce interference, and can lead to performance degradation.

The U.S. Army Research Laboratory (ARL) initiated a Science and Technology Objective to develop information system interface solutions to reduce cognitive workload, enhance situation awareness, shorten decision-making times, and improve decision accuracy. Experimental approaches have been developed, based on identification of operational task demands, ratings of task workload (visual, audio, cognitive, speech, physical), and theory-based predictions, drawn from Multiple Resource Theory (Boles, 2001; Wickens, 2002; Wickens, 1992; Wickens & Hollands, 2000). The objective is to apply multi-modal interventions to task situations typified by high and conflicting workload.
It has been emphasized that current automation feedback relies heavily and increasingly on the focal visual modality (Sarter, 2000; Wickens, 2002). It has also been argued, and demonstrated, that multimodal interventions using non-visual pathways can be used to ameliorate the task demand (Gilliland & Schlegel, 1994; Raj et al., 1998; Sarter, 2000, 2001, 2002; Sklar & Sarter, 1999). As a result, the use of other modalities (e.g., in the form of tactile, audio, or peripheral visual cues) is being explored for numerous military applications. Experimental results have shown that the most complex variants of these non-visual displays are successful in air and space applications (McGrath et al., 2004; Raj et al., 1998; Raj, Kass & Perry, 2000; Rochlis & Newman, 2000; Rupert, 2000a, 2000b; Van Erp et al., 2003, 2005, Bronkhorst et al., 1996). The use of the tactile modality to present information is discussed more elaborately in the next paragraph.

1.1 Tactile Displays

Offloading the visual and auditory channels without increasing workload is the main purpose of presenting information in a different modality: for instance through the sense of touch. In this modality, the information can be presented to the user in the form of vibrations on the skin. The Multiple Resource Theory (Wickens, 1984) predicts that this (vibro)tactile information processing channel can be used simultaneously with visual and auditory information. The goal can be to present more information than a person could have processed using only eyes and ears, or to offload information from other channels (present information tactilely, instead of visually or auditorily).
Fundamental research on the perception of vibrotactile stimuli has focused on coding principles, differentiating between multiple tactile signals and discerning directional information (Van Erp & Van den Dobbelsteen, 1998; Van Erp & Vogels, 1998). Van

Erp and his colleagues (1998) have investigated localization of tactors, comparing actual placement with reported sensation of vibration, and have performed a series of experiments relevant to placement and intensity of tactors (Van Erp, 2005) and alternative approaches to coding information (Van Veen & Van Erp, 2004). The location of the tactors plays a key role. For instance, Gilliland and Shlegel found limited usefulness of tactile displays on the head for pilot threat warning (1994). Tactile systems have proved to be particularly effective when other information channels are overloaded or distorted (e.g., in a noisy environment or when visibility is low). Several studies have demonstrated the usefulness of tactile information input in multi-task situations (Hopp et al., 2005; Sarter, 2002, 2001; Sklar & Sarter, 1999; Van Erp et al., 2003).

1.2 Tactile land navigation

Tactile displays have been designed, built and tested with a main focus on intuitive applications in orientation and navigation tasks. Van Erp (2005) showed that a localized vibration on a waist belt could easily and accurately be interpreted as a direction in the horizontal plane. Inferring direction from a vibration around the waist or torso (a relatively stable body part) is very intuitive: the 'tap-on-the-shoulder' principle. This allows presenting navigation information with a higher resolution than just 'turn left' or 'turn right', and with lower cognitive load (opposed to using a compass or alpha-numeric display, for instance). This concept of using vibrotactile displays for orientation and navigation has also been tested in cars, cockpits, speedboats, and the International Space Station (Van Erp & Van Veen 2004; Van Erp et al. 2003; Dobbins & Samways, 2002; Van Erp & Van Veen, 2003) and in personal navigation (Van Erp, Spapé & Van Veen, 2003; Van Erp & Duistermaat, 2005). For land navigation by dismounted soldiers, the tactile information does not interfere with the auditory modality which is being used to maintain (radio) communication or the visual modality that is being used to scan the battlefield to maintain situation awareness.

In waypoint navigation, two aspects are important: direction to and distance from the waypoint. The design of a tactile waypoint navigation display requires finding an optimal translation of direction and distance into a tactile 'picture'. Direction information alone can be sufficient in case the waypoint can be easily identified when reached. Otherwise, distance information is essential. Furthermore, distance information may be important if specific preparations are required before reaching the waypoint.
While a vibrotactile display can easily portray direction by using the parameter 'location', portraying distance might not be so intuitive. The preferred display parameter to code distance is not a priori clear. Two other tactile parameters, 'frequency' and 'amplitude', are not very well suited to code information. The number of perceptually distinguishable levels for these parameters is only in the order of 5-7 (Van Erp, 2002). However, the skin is very sensitive to temporal aspects of vibrotactile stimulation (Van Erp & Werkhoven, 2004) and timing therefore seems to be the preferred parameter for coding distance. The choice for timing (or actually on/off rhythm) is also supported by examples of best practices. Chiasson et al. (2002) used three different rhythms to enlarge the 90° display resolution to indicate 30° segments, Van Erp et al. (2003) and McGrath et al (2004) used rhythm to indicate the amount of drift or the airspeed in their helicopter hover displays, and Bosman et al. (2003) found that length of pulse trains are a better coding than intensities in a pedestrian guiding system.

For the current tactile land navigation experiment, location on the body was used as parameter to code direction, while rhythm was used as parameter to code distance.

1.3 Overview of the experiment

The technology and effectiveness of vibro-tactile cues as alerts and navigation cues have been demonstrated over several years. This progress is of particular interest to the Army Science and Technology Objective, which oversees investigation of display-based interventions to enhance small unit situational understanding and decision-making. Tactile cues have been proven particularly useful when workload on other information processing channels (e.g., visual, auditory) is high, when there are high multi-tasking demands, and when visibility is low. It is expected that tactile navigation cues will enhance soldier performance in land navigation scenarios. Therefore, the US Army commissioned TNO Defence, Security and Safety to investigate the potential of a tactile display for land navigation.

This study is a collaboration between ARL and TNO Human Factors (Soesterberg, The Netherlands). The study follows a previous investigation of the PTN system, in which it was compared to the Army AN/PSN-11 Precision Lightweight GPS Receiver (PLGR) and to the compass system during the day (Van Erp & Duistermaat, 2005). In that study, the PTN system proved to be as effective as the PLGR, and more effective than the compass. However, the cognitive and visual load in that study were low. In the current experiment, the visual load was increased by performing the land navigation trials at night, and adding a target detection task (to investigate effectiveness when the visual channel is employed in other tasks, and visibility is reduced). Soldiers will perform land navigation within a moderate workload context, with a visual search task, when visual information is reduced. The soldiers were forced to walk in less of a straight line than in the first study (because of the obstacle on the route and the target detection task), and an off-limits area along the routes was added.
In the current study, land navigation performance with the PTN system is compared to performance with the PLGR and with the Land Warrior Head-up Navigation Device (LWS).

1.4 Objectives

The main goal of this land navigation study using a tactile display is to demonstrate and assess effectiveness of the PTN system, as compared to PLGR and the LWS system, during night operations. The major foreseen advantages in the tactile application are that the PTN system frees the eyes and hands of the soldier.
Soldier’s navigation performance will be measured to answer the following questions:

How does the use of the PTN system compare with the PLGR and the LWS in:
- reaching each waypoint
- speed of course completion
- rerouting around terrain obstacles
- avoiding off-limits areas
- detecting targets.

2 Method

2.1 Participants

Twenty-four soldiers from the 29th Infantry Regiment and the 3rd Battalion, 11th Infantry Regiment participated in the study. Although the unit was officially requested for troops, it was made clear that soldier participation in the experimentation would be voluntary. The participants were given an opportunity to review the experiment objectives and have any of their questions answered by the investigators. They were briefed on the objectives and procedures, as well as on the tactile system and LWS system. They were also told how the results would be used and the benefits the military can expect from this investigation. After having received all the information, they signed the Volunteer Agreement Affidavit indicating their informed voluntary consent to participate, and the soldiers completed a medical status form. The soldiers were informed that if they chose not to participate, they could convey that choice privately to the experiment manager (who would inform that soldier's unit supervisor, without elaboration, that the soldier did not meet experimental criteria).

2.1.1 Demographics

Demographic data was taken for each soldier. The soldiers ranked from E1-E7, and had an average service time of 54.13 months (min. 5, max. 205, SD 64.37). The average age as 27.17 years old, ranging from 20 to 35 (SD 4.37).

2.1.2 Training

The soldiers that participated were in a military occupational specialty that requires land navigation skills. No further specialized experience was required for the experiment. An ARL representative showed the soldiers how to negotiate the courses safely and trained the soldiers on specific procedures as required. The ARL representative also trained the soldiers on the use of the PLGR and the LWS system. A representative of TNO-HF trained the soldiers on the use of the PTN system. In a classroom training session the outlines of the experiment were explained. The different routes were explained, as well as the navigation task and target detection task that the soldiers had to perform. After this classroom training session, the soldiers conducted practice field trials with each type of navigation equipment.

At the end of the training session a questionnaire was administered to evaluate the effectiveness of the training (see Appendix A). The soldiers rated aspects of the training on a scale of 1 to 7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective), and gave an indication of how well they thought they would perform using the three systems, on a scale of 1 to 7 (very poorly, somewhat poorly, slightly poorly, neutral, slightly well, somewhat well, very well). The soldiers also rated the three systems in terms of expected usefulness for specific military operations, assuming that the system works perfectly, on a scale of 1 to 7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective).

2.2 Instruments and apparatus

2.2.1 Night vision system

All three navigation systems were supported with the use of a night vision system (Night Vision Goggles: NVG). The PV-14 monocular system was used, which is currently also fielded for operational use.

2.2.2 AN/PSN-11 Precision Lightweight GPS Receiver (PLGR)

The Army Precision Lightweight GPS Receiver (PLGR; Figure 2.1 A) is a hand-held GPS receiver, featuring selective availability/anti-spoofing (SA/A-S) and anti-jam capability. It weighs approximately two pounds (approx. 1 kg), with an alpha-numeric screen that displays information on direction and distance to waypoint. It has four different modes and a menu system with sequential commands to initiate functions. Figure 2.1 B shows a PLGR information display that indicates waypoint number, position accuracy, current heading in degrees, direct azimuth, and steering angle, with example values below. Figure 2.1 C provides example values for range (distance to waypoint), estimated time to waypoint, elevation difference, and minimum miss difference (same as range unless you are off course).

<table>
<tr><td rowspan="2"></td><td>
</td><td></td></tr>
<tr><td>WP002 30m
TRK 020.5M
AZ 210.0M kph
STR >190.5 ⇕P</td><td>RNG 60.0m
TTG 0020:15
ELD +00003.0m
MMD2 60.0 ⇕P</td></tr>
<tr><td>A</td><td>B</td><td>C</td></tr>
</table>

Figure 2.1 – The PLGR navigation system.

<u>Land navigation using the PLGR</u>

Navigation using the PLGR requires training and practice. The different modes and the extensive menu system require high cognitive effort to use the system. All the information is on the alphanumeric display, so the soldier has to ‘translate’ these numbers into information about his surroundings, to build up good situational awareness (high cognitive load). Also, information about time to go and minimum miss distance is not available if the operator is not moving. Thus the soldier has to look at the visual display while walking the terrain. This leaves very little visual resources to attend to the surroundings while the soldier is checking the display (high visual load). Since the PLGR system is hand-held, it also interferes with other manual tasks, such as handling the weapon or pushing away branches (high manual load).

2.2.3 *Land Warrior Head-Up Navigational System (LWS)*

The Land Warrior navigational system (LWS) displays navigational information on a helmet mounted display (HMD). In addition to the HMD, the system consists of a computer box, a navigation box, battery pouches, a control unit, and the interconnecting cables. These components can be mounted on body armour or on standard load-bearing equipment. The LWS system operates using a GPS receiver and a dead reckoning device.

Land navigation using the LWS system

The Land Warrior system is a head-mounted, visual based soldier information system. It provides the soldier with a head-mounted visual display, on which different types of information can be presented (e.g., pictures of specific buildings or areas, information on unit position, etcetera). For this experiment, the navigation information was used, and the display showed a map of the area. On the map the waypoints were indicated by icons and the soldier's own position by a different icon. The display was presented to one eye (monocular); the night vision goggle was in front of the other eye. The soldier always had the map with his own position in relation to the waypoints at his disposal (and thus knew where he had to go). Compared to the PLGR system, the LWS system has a more intuitive display (map vs. alphanumeric), thus lower cognitive load. Except for having to adjust, or move the monocular to or away from the eye, the system is hands-free (moderate manual load). However, the visual load for the soldier is high, especially when the night vision goggles also have to be used.

2.2.4 *The TNO-HF Personal Tactile Navigator System (PTN)*

The Personal Tactile Navigator, or PTN, is a personal navigation system that uses the sense of touch. The directional information (where to go) is presented through localized vibrations on the body of the user. The location of the vibrating element on the body of the user corresponds to the direction of the waypoint. So to arrive at a specific location, the user can just "follow the buzz".

The PTN system consists of six elements, which are depicted schematically in Figure 2.2.

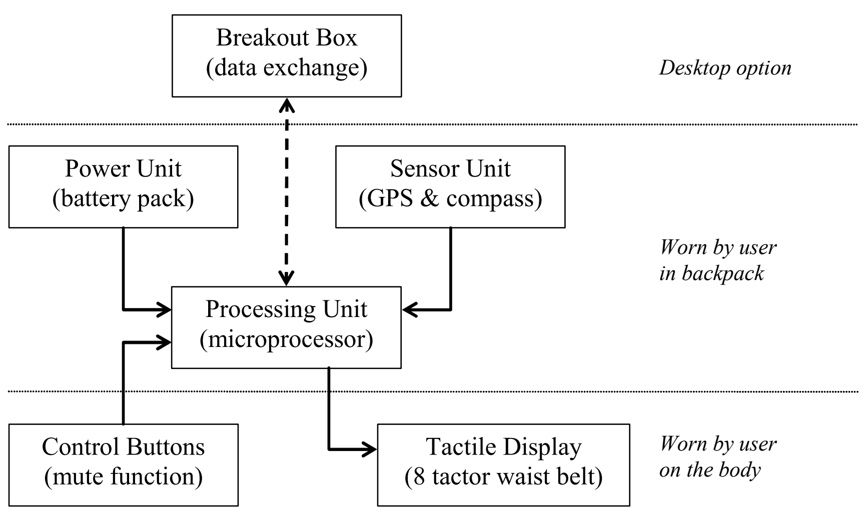

Figure 2.2 – A schematic overview of the PTN system.

Except for the breakout box, the PTN system was worn by the soldier. The breakout box is a ‘desktop option’ that contains connections for a keyboard, mouse, VGA monitor, floppy drive and Ethernet. It was used by the TNO experimenters to enter the experimental conditions at the beginning of the experiment (subject number, route to be walked), and to backup data from the PTN system. When the soldier walked the route, the breakout box was disconnected from the rest of the PTN system.
The sensor unit, processing unit and power unit have individual aluminium housings. The sensor unit was mounted on top of a backpack, to ensure proper GPS reception. The same backpack was also used to carry the power unit and the processing unit. The tactile display was worn on the body, around the waist over the underclothing of the soldier. The control button panel was carried in one of the pockets of the soldier’s uniform (see Figure 2.3).

Figure 2.3 – Left: picture of soldier wearing PTN. Top right: picture of the tactile display (waist belt) with the tactors. Bottom right: picture of the PTN system equipment (breakout box, microprocessor, sensor unit, battery unit).

The sensor unit consists of a GPS sensor (Garmin GPS 35-HVS) and an electronic compass (Honeywell HRM 2300). The sensor unit provides data on the current position (GPS) and heading (electronic compass) of the user. Only in case the heading data of the compass is not reliable (when the compass is tilted more than 15 degrees from horizontal), the heading data from the GPS is used. Since the latter is based on comparing subsequent positions, the GPS data alone is not sufficient to (a) detect heading changes without changing location (in other words, you have to walk for the GPS to be able to tell heading) and (b) provide accurate feedback during fast course changes (because of the 1 Hz update rate a delay will occur). The data from the digital compass however can be used to signal a course deviation even without a GPS update on exact location (because the update rate of the GPS unit is 1 Hz but the system ran at 10 Hz or more), and the compass can detect heading without moving.

The processing unit (a 486 DX Tiqit matchbox PC) compares the current position and heading of the user to the active waypoint of the stored route (comparing where the user is and what direction he faces, to where the waypoint is, resulting in where the user has to go). The following variables were stored in the processing unit:

- Time and speed (by GPS time)
- GPS position and route (latitude and longitude)
- Compass heading and inclination (if the inclination was more than 15 degrees the compass heading is not reliable, in that case the heading of the GPS is used)
- Used heading (by compass or by GPS)
- Angle between the waypoint and the heading of the user
- Which tactor vibrates
- The active waypoint.

The processing unit calculated the direction that the soldier had walk in to arrive at his waypoint. This direction was presented on the tactile display; the tactor that corresponded to that direction ‘buzzed’ (so if the soldier had to go left, a tactor at the left side would ‘buzz’).
The tactile display was an adjustable waist belt with small vibrating elements (the tactors) on the eight cardinal and oblique positions around the waist (see Figure 2.3 and 2.4). The position of the tactors inside the waist belt was also adjustable, so they could always be placed on the cardinal and oblique positions on the body, irrespective of body size. The waist belt was worn over the underclothing of the soldier. The tactors were 1.3 V vibrating DC motors (JinLong Industries) housed in rectangular PVC boxes, with a contact area of 1.5 by 2.0 cm and a vibration frequency of 155 Hz. The resolution of the display (i.e., 8 tactor positions for 360°) was in between the minimum required (i.e., two tactor positions: one tactor for left and one for right) and the limit of direction perception on the torso (as shown by Van Erp (2005) to be in the order of 10°).
The processing unit, sensor unit and tactile display received their power from a rechargeable NiMH battery pack (14.4 V, 3.3 Ah, fused).

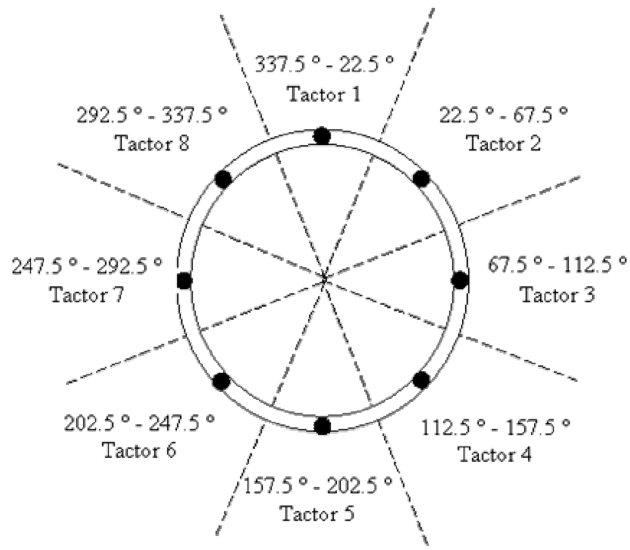

Figure 2.4 – The eight tactor positions, and the angles determining the active tactor (corresponding to the direction of the active waypoint).

Land navigation using the PTN system

The PTN system is very intuitive, has a very low cognitive load, and requires little or no training. The directional information is presented on the tactile display (the waist belt around the torso), thus enabling hands-free navigation (low manual load). The tactile display provides information continuously, and requires no visual attention (no visual load). The soldier therefore also has his eyes free to perform other tasks, such as scanning the environment or target detection.

In the current experiment, information about navigational aspects (direction and distance) and about being in off-limits area (described in paragraph 2.3) were both presented on the tactile display.

Four navigational aspects were coded (see also Table 2.1):

- the direction of the waypoint, indicated by the location of the vibrating tactor (each tactor had a 45° angle, if the waypoint was within that angle, that corresponding tactor would buzz: see Figure 2.4)
- distance to the waypoint, indicated by a single buzz when the user was further than 50m from the waypoint, and a double buzz when the user was within a radius of 50m from the waypoint
- when walking on track, the front tactor would buzz at a slower pace than the other seven, to make it distinct from the others (as a redundant cue besides location), and to lower the amount of tactile stimulation without losing confirmation that the system is working and the heading error is small
- the arrival at a waypoint, indicated by a long vibration of all the tactors in the belt (simultaneously).

The values that were chosen for coding the navigation information (as mentioned in Table 2.1), were based on several pilot studies.

Table 2.1 Coding of navigational aspects.

	Tactor pattern	Vibration sensation
Distance > 50 m	Tactor 1: 200 ms on, 1800 ms off Tactor 2-8: 200 ms on, 800 ms off	Tactor 1: single buzz every two seconds Tactor 2-8: single buzz every second
15 m < Distance < 50 m	Tactor 1: 100 ms on, 200 ms off, 100 ms on, 600 ms off Tactor 2-8: 100 ms on, 100 ms off, 100 ms on, 200 ms off	Tactor 1: double buzz every second Tactor 2-8: double buzz every half of a second
Distance = 15 m	All tactors: 3 sec. on	All tactors: long buzz

Besides the navigational aspects, information about the off-limits area was also presented on the tactile belt (see also Table 2.2). The soldier would receive a warning signal when he entered the off-limits area. This warning signal continued to be active as long as he remained in the off-limits area. The warning signal consisted of 'blocks' of 4 short vibrations by all tactors. In between two blocks of the warning signal, information was presented on how to get out of the off-limits area. For that 'escape signal', one tactor vibrated, pointing the shortest way out of the off-limits area, back on track. These two blocks of signals (the warning signal block and the escape signal) alternated each other until the user walked out of the off-limits area, then the warning signal stopped. The escape signal still continued to be active, until the user was back on track. Once back on track, the direction of the waypoint was indicated again.

Table 2.2 Coding of the off-limits information.

	Tactor pattern	Vibration sensation
In the off-limits area	Warning signal block: all tactors 4 times 200 ms on, and 100 ms off, then 800 ms off Alternated by: Escape signal block: one tactor indicating direction to track: 4 times 100 ms on, and 100 ms off, then 1200 ms off	Two alternating signals: The warning signal, four short buzzes in a row by all tactors (for 1 second) And: The escape signal, four short buzzes in a row by one tactor (directional information, every 2 seconds) (see also Figure 2.5)
Out of off-limits area, not back on track	Escape signal block: one tactor indicating direction to track: 4 times 100 ms on, and 100 ms off, then 1200 ms off	four short buzzes in a row by one tactor (directional information, every 2 seconds)
Back on track	Standard navigational information	Standard navigational information (see Table 2.1)

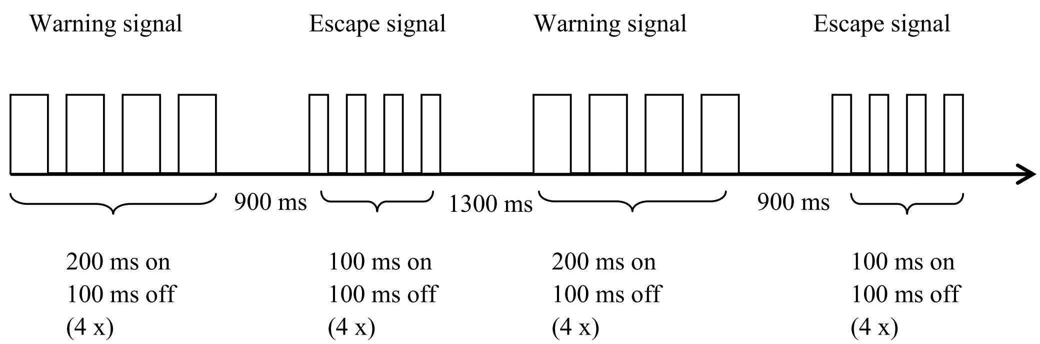

Figure 2.5 – Timing of the warning signal and escape signal.

2.3 Land navigation course

The experiment was conducted at the Ft. Benning Primary Leadership Development Course (PLDC). Three equivalent land navigation courses were used. The courses were triangle-shaped, and consisted of three waypoints. Each waypoint was signified by a 5 foot post identified by a number. The three lanes (between the waypoints) were approximately 500 meters in length, creating routes of 1500 meters on average.
Each route consisted of three different lanes:

- Obstacle avoidance lane: an obstacle on the lane prevented the soldiers from negotiating in a straight line (obstacles were an area with buildings, a car parking area and a swamp).
- Narrow lane: 40 meter wide walking lane (20 meters on either side of the straight line between two waypoints). Outside the walking lane was off-limits area, soldiers were instructed to keep out of the off-limits area
- Wide lane: 100 meter wide walking lane (50 meters on either side of the straight line between two waypoints). Outside the walking lane was off-limits area, soldiers were instructed to keep out of the off-limits area.

Each lane included rolling terrain, woodland, open areas, and dense undergrowth. Targets (10 static silhouette targets, 3 live targets) were positioned along the narrow and wide lanes (no targets were on the obstacle avoidance lane). The routes are depicted in Figure 2.6 and Table 2.3.

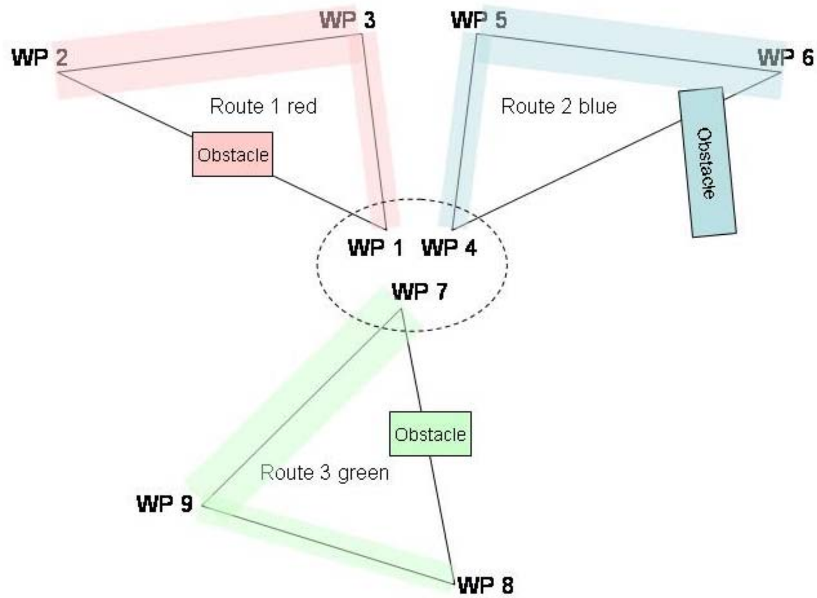

Figure 2.6 – Routes. The start point for the routes (WP1, WP4, and WP7) was actually at the same GPS location; however for clarity of the picture the routes are depicted separately.

Table 2.3 Lane characteristics.

		Lane type	# live targets	# silhouet targets
Lane	**Route 1**			
1	WP 1 – WP 2	Obstacle	0	0
2	WP 2 – WP 3	Wide	3	10
3	WP 3 – WP 1	Narrow	3	0
	Route 2			
1	WP 4 – WP 5	Narrow	3	0
2	WP 5 – WP 6	Wide	3	10
3	WP 6 – WP 4	Obstacle	0	0
	Route 3			
1	WP 7 – WP 8	Obstacle	0	0
2	WP 8 – WP 9	Narrow	3	0
3	WP 9 – WP 7	Wide	3	10

2.4 Measures

<u>Soldier evaluation of the navigation systems</u>

After the soldier completed a navigation route with a system, he filled out a questionnaire about that navigation system (this was repeated for all the routes/systems). The soldiers rated their performance with each system on a 1-7 scale, on effectiveness of various aspects of the systems and relevance of the systems for various military operations. After the soldiers had used all three systems, they rank-ordered the systems with regard to various aspects of performance and preference (see Appendix C).

Navigation performance

Also, measures were taken for route completion and target detection. These navigation performance measures will be analysed and reported by the Army Research Laboratory, and are therefore not dealt with in this report, but only described here briefly.

For route completion, measured were: if the soldiers reached the waypoints; if the soldiers reached the waypoints within the allotted time; the time it took the soldiers to complete the land navigation lanes; the mean deviation from the navigation lane (which can indicate walking around an obstacle). Also, it was measured whether the soldier entered the off-limits area. The GPS file recorded by the data collector was used to analyze the measures stated above. Also, the start and end time of a navigation lane was recorded by the data collector with a stopwatch, and they noted if a soldier reached a waypoint. For target detection, measured were: the number of silhouette targets the soldier detected on the lanes; the number of human targets the soldier detected on the lanes; the distance of the soldier to the target, at the moment of detection. These measures were also noted by the data collector.

2.5 Procedure

The experiment was held at night (started at 6 pm and ended around 1 am), over a data collection period of two weeks. Three soldiers participated per night. Each night started with a classroom training session, in which the complete experiment was explained to the soldiers (including the configuration of the routes, number of targets, time limit on navigation, etcetera). Directly after the classroom training, the soldiers were trained on and practised with the three navigation systems and the night vision system. After training and practice the soldiers completed questionnaires on self-assessment of skill and evaluation of training (see Appendix A).

Navigating the routes started after sunset. All soldiers completed three routes, one with each system. The type of navigation system was counterbalanced with navigation route and order. A data collector was assigned to each route, and followed each soldier as he completed his route, to record data. Three soldiers could be run simultaneously, as there were three separate but equivalent land navigation routes.

The soldiers had to navigate from waypoint to waypoint (see also Figure 2.6). On the lanes, they either had to

- negotiate around an obstacle
- detect as many targets as possible, and stay within a 40 meter wide lane
- detect as many targets as possible, and stay within a 100 meter wide lane.

The soldiers were instructed to move as quickly as possible. They also had to laser a target (with their weapon) to indicate detection of the target. The soldiers were particularly encouraged to find the human target along the route. A land navigation lane ended when the soldier either (a) reached the waypoint, (b) moved 50m beyond the waypoint without detecting it, or (c) failed to reach the waypoint within 30 minutes. If the soldier could not find the waypoint, the data collector documented this and led the soldier to the next waypoint, from which he could start navigating the remaining lane(s). After completing each route the soldier responded to questionnaire items about his experiences with the navigation device (see Appendix C) and waited until the next route was ready for the next iteration.

Soldiers were assigned to systems and routes according to the matrix presented in the Table presented in Appendix B. A data collector accompanied (followed) each soldier on each trial to record the soldier's route on a GPS tracking device (Garmin E-Trex Legend C) and to register the number of targets found. The time to complete each lane and the number of targets found was also recorded by the data collector.

3 Results

The navigation performance data (route completion and target detection) will be analyzed by the Army Research Laboratory, and will therefore not be discussed here.

3.1 Training evaluation

After the training, the soldiers rated aspects of the training on a scale of 1 to 7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective), and gave an indication on how well they thought they would perform (very poorly, somewhat poorly, slightly poorly, neutral, slightly well, somewhat well, very well). The results are depicted in Figure 3.1.

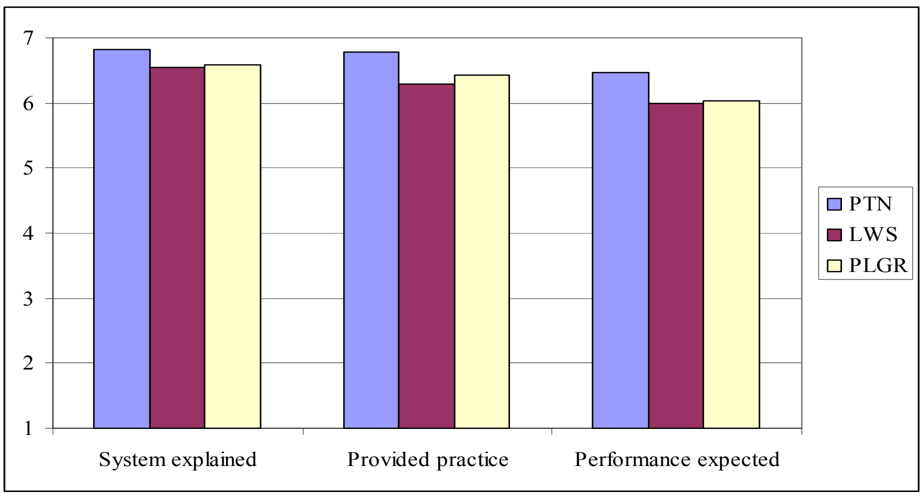

Figure 3.1 – Evaluation of training.

These results were not statistically significant.
The soldiers also rated the three systems in terms of expected usefulness for specific military operations, assuming that the system works perfectly, on a scale of 1 to 7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective). See Figure 3.2.

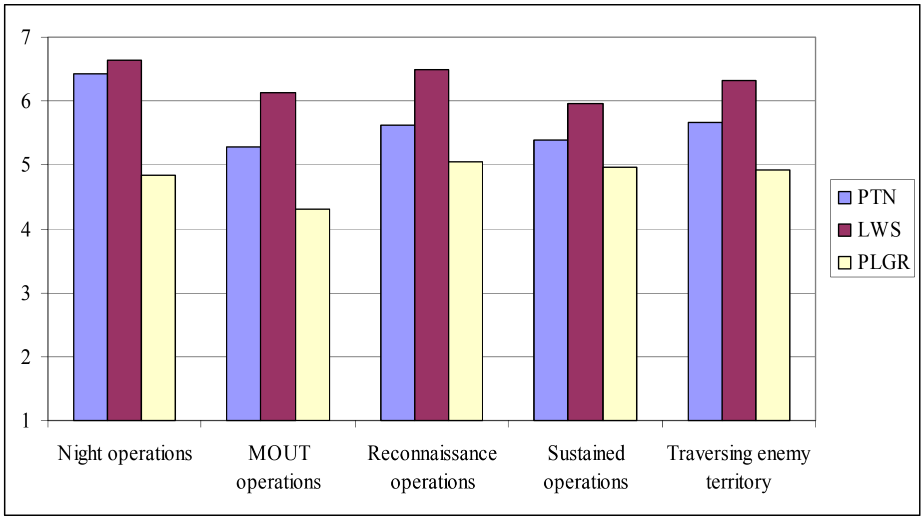

Figure 3.2 – Expected usefulness of navigation systems for military operations.

An analysis of variance showed a significant system*operation interaction effect, $F(8,176)=2.03$, $p<.05$. The post hoc Tukey HSD test revealed significant differences (all $p<.001$) for:

- Night operations: PTN vs. PLGR and LWS vs. PLGR
- MOUT operations: PTN vs. PLGR and LWS vs. PLGR
- Reconnaissance operations: LWS vs. PLGR
- Sustained operations: LWS vs. PLGR
- Enemy territory: LWS vs. PLGR.

3.2 Device evaluation

After navigating each route, the soldiers evaluated the navigation device they used on that route.
For the PTN system, soldiers rated different aspects of the ease of use on a scale from 1 to 7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective). The soldiers also rated the strength of the vibration, ranging from 1 (too weak), through 4 (ideal) to 7 (too strong). These results are indicative and are presented in Figure 3.3.

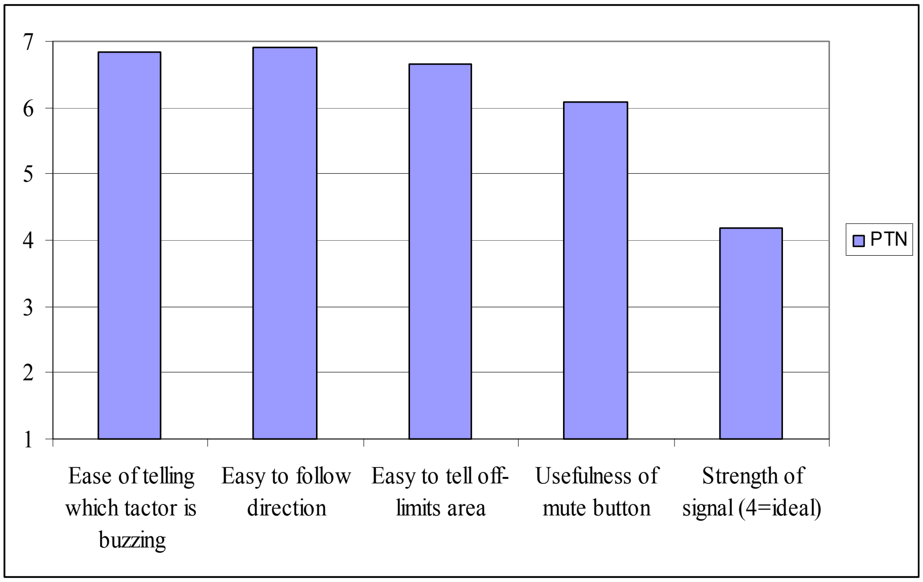

Figure 3.3 – Ease of use of the PTN system.

All devices were rated for the effectiveness on several navigation aspects: staying on route, rerouting around large terrain obstacles, watching for targets, watching for terrain obstacles, avoiding the off-limits area, finding the waypoints, allowing general situation awareness, and allowing hands-free operation. The items were rated on a scale of 1-7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective). See Figure 3.4 and Table 3.1.

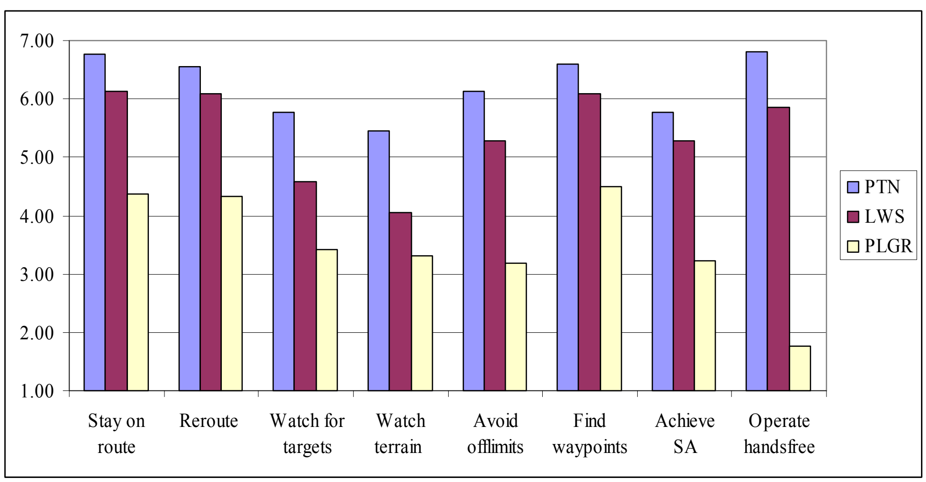

Figure 3.4 – Ratings of effectiveness of the navigation devices.

Table 3.1 Ratings of effectiveness of the navigation devices.

Aspect	F-value	p-value	Post-hoc Holmes-Bonferroni		
			PTN vs. LWS	PTN vs. PLGR	LWS vs. PLGR
Staying on route	F(2,40)=27.20	p<0.001	p<0.01	p<0.001	p<0.001
Rerouting	F(2,40)=19.16	p<0.001	not signif.	p<0.001	p<0.01
Watching targets	F(2,38)=8.81	p<0.01	not signif.	p<0.01	not signif.
Watching terrain	F(2,40)=10.07	p<0.001	p<0.025	p<0.001	not signif.
Avoid off-limits	F(2,40)=35.61	p<0.001	not signif.	p<0.001	p<0.001
Finding waypoints	F(2,40)=19.64	p<0.001	not signif.	p<0.001	p<0.01
Achieve general SA	F(2,40)=18.82	p<0.001	not signif.	p<0.001	p<0.001
Operate handsfree	F(2,40)=131.38	p<0.001	p<0.025	p<0.001	p<0.001

All devices were rated for several characteristics of the device: easiness to learn, easiness to use, ease of telling where you are located, ease to stay on the correct route, and the accuracy of guidance of the system. The items were rated on a scale of 1-7 (very bad, bad, somewhat bad, neutral, somewhat good, good, very good). See Figure 3.5 and Table 3.2.

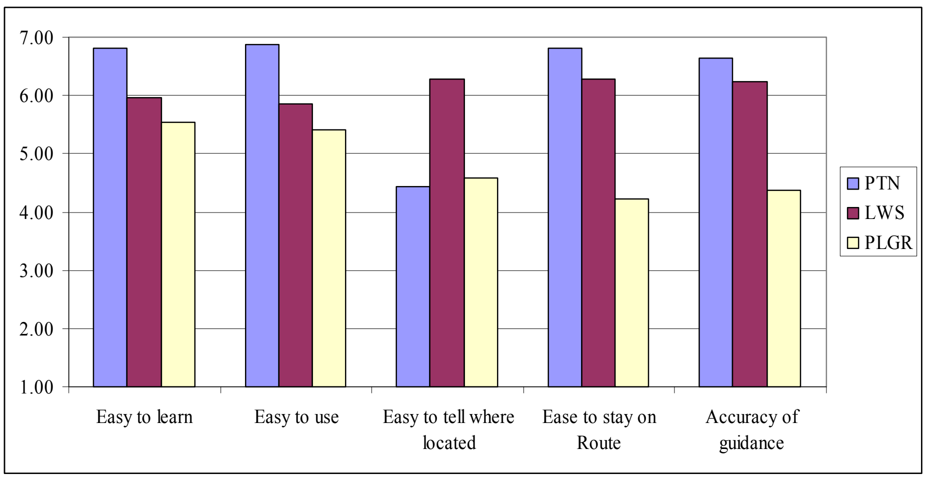

Figure 3.5 – Ratings of device characteristics.

Table 3.2 Ratings of device characteristics.

Aspect	F-value	p-value	Post-hoc Holmes-Bonferroni		
			PTN vs. LWS	PTN vs. PLGR	LWS vs. PLGR
Easy to learn	F(2,40)=5.58	p<0.025	p<0.01	p<0.01	not signif.
Easy to use	F(2,40)=6.34	p<0.025	p<0.01	p<0.01	not signif.
Easy to tell where located	F(2,40)=6.16	p<0.01	p<0.01	not signif.	p<0.01
Easy to stay on route	F(2,40)=33.43	p<0.001	p<0.025	p<0.001	p<0.001
Accuracy of guidance	F(2,40)=17.74	p<0.001	not signif.	p<0.001	p<0.01

The soldiers rated all the systems for their expected use and effectiveness in several military operations. They were asked to rate the system, assuming the system works perfectly, on a scale from 1 to 7 (very ineffective, somewhat ineffective, slightly ineffective, neutral, slightly effective, somewhat effective, very effective). See Figure 3.6 and Table 3.3.

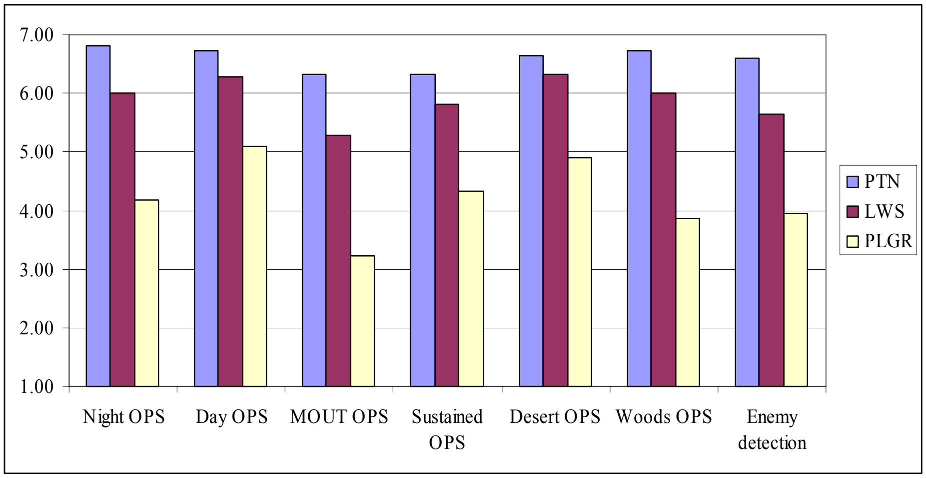

Figure 3.6 – Expected usefulness in military operations.

Table 3.3 Expected usefulness in military operations.

Aspect	F-value	p-value	Post-hoc Holmes-Bonferroni		
			PTN vs. LWS	PTN vs. PLGR	LWS vs. PLGR
Night operations	F(2,40)=17.61	p<0.001	p<0.025	p<0.001	p<0.01
Day operations	F(2,38)=10.06	p<0.01	not signif.	p<0.01	p<0.025
MOUT operations	F(2,40)=31.85	p<0.001	p<0.01	p<0.001	p<0.001
Sustained operations	F(2,40)=12.73	p<0.001	not signif.	p<0.01	p<0.01
Desert operations	F(2,40)=10.46	p<0.01	not signif.	p<0.01	p<0.01
Woods operations	F(2,40)=26.16	p<0.001	p<0.025	p<0.001	p<0.001
Enemy detection	F(2,40)=17.11	p<0.001	p<0.01	p<0.001	p<0.01

At the end of the complete experiment (after all soldiers finished all navigation routes with all devices), the soldiers were asked to rate the three systems on several navigation aspects from 1 to 3, compared to each other (see Appendix C4). The instances where the system was rated as 1 (= best system) were counted and depicted in Table 3.4.

Table 3.4 Number of times the device was rated with 1.

	PTN	LWS	PLGR	Total responses
Staying on route	14	6	0	20
Rerouting	11	8	1	20
Watching targets	16	3	0	19
Watching terrain	18	2	0	20
Avoid off-limits	16	4	1	21
Finding waypoints	13	7	0	20
Easy to learn	20	1	1	22
Easy to use	18	1	3	22
Allowing SA	18	3	2	23
Easy to tell where located	0	19	1	20
Easy to stay on route	13	9	1	23
Accuracy of guidance	9	10	2	21
Best overall system	14	9	0	23

4 Conclusions and discussion

This chapter focuses on the soldiers' experiences with the PTN system, and will therefore not discuss the data regarding the PLGR or LWS system (only when compared to the PTN system).
As can be seen from the questionnaire data, the soldiers were very positive about the PTN system. In all cases the PTN system was rated higher than the PLGR, and in most cases the PTN system was rated higher, or as high as the LWS system. This was also reflected in the soldiers' comments about the navigation systems. The soldiers stated they liked the hands-free and eyes-free aspect of the PTN system best, and the fact that the system was easy to use, and provided correct and accurate navigation information. Some illustrative comments about the system's characteristics were
"If you were injured to the eyes or lost your eye glasses the device guides you pretty much flawlessly with very limited vision"
"Hands free operation of this navigation aide was a huge plus. Provided a very effective means to stay on my line of travel/route without being a distraction"
"You could be a soldier and a navigator at the same time without sacrificing anything"
"I didn't feel like I was even land navigating"

A remarkable comparison can be made between the expected usefulness of the different systems in military operations, as rated by the soldiers before and after using the systems on the navigation routes. After the training and practice session, the soldiers were asked to indicate how useful the system would be for specific military operations (see Figure 3.2). This was before the soldiers actually walked the navigation lane with the system. As can be seen, the soldiers expected the LWS system to be the most useful or effective for most operations (no difference between LWS and PTN system for night ops). However, after finishing the land navigation route with the system, they rated the PTN system as expected to be the most useful or effective in military operations, and not the LWS (Figure 3.6).
This could be explained by the fact that soldiers experienced some downsides of the LWS system, such as lenses fogging up, a delay in the image update rate, night-blindness, and difficulty to walk while viewing the heads-up display. All these disadvantages are related to the visual display, and are exactly the issues why in the PTN system, the information in presented on a tactile display. However, a visual display does have the advantage of providing an overview of one's position in the surroundings, or one's position in relation to objects in those surroundings (waypoints, buildings, enemy territory, etcetera).

A distinction must be made between two types of information which can both be termed as 'situation awareness': local guidance versus global awareness. Local guidance refers to information about the surroundings close by: the question "what does my surrounding look like, what do I see, are there other people nearby", etcetera. Acquiring this kind of information is improved by displaying the navigation information on a tactile display. Because of the low visual load, the eyes can be used to scan the environment for building up the picture of "where am I, and what am I surrounded by". This is reflected in Figure 3.4, where the PTN (and the LWS system) has a high rating for being able to achieve situation awareness.
However, conveying information about one's position in (relation to objects in) the surroundings (the questions "how far am I from a waypoint, what is outside my field of view"), is difficult to accomplish with a tactile display, especially when only one

dimension is used such as in this study (tactors only in the horizontal plane). A visual display is much better suited for this kind of global awareness information. This is also reflected in the soldiers' ratings of device characteristics (Figure 3.5), in which the soldiers clearly indicate that the LWS system (with a visual display) worked much better in telling where they were located. On the LWS system, the waypoints and the soldier were both displayed, so the soldier could always see how far he was from the waypoint. With the PTN system, it was only indicated whether the soldier was further or closer than 50m from the waypoint. The desire for a visual display (especially to indicate one's position in the surroundings), was also reflected in the soldiers' comments. On the question 'what would you improve to the PTN system', some illustrative comments were:
"Including a device that shows you where you are at anytime"
"ability to read and mark points using info screen of some type"
"Integrate it with a visual navigation system".

4.1 Follow-up study

The positive experiences with the PTN system and the visual display of the LWS system, led to the formation of a proposal for a follow-up study on the effectiveness of a multi-modal navigation system. In this follow-up study, the combination of displaying situational information visually (as in the LWS system), and the navigational information tactilely (as in the PTN system) will be tested. As this combination integrates the best aspects of both systems, it is expected to show further improved performance, where soldiers can rely on tactile navigation information, and maintain situational awareness by occasionally checking their visual display.

5 References

Boles, D.B. (2001). Multiple resources. In W. Karwowski (Ed.), *International Encyclopedia of Ergonomics and Human Factors* (pp. 271-275). New York: Taylor & Francis.

Bosman, S., Groenendaal, B., Findlater, J.W., Visser, T., De Graaf, M. & Markopoulos, P. (2003). GentleGuide: An Exploration of Haptic Output for Indoors Pedestrian Guidance. *Proceedings of the Mobile HCI*, Udine, Italy.

Bronkhorst, A.W., Veltman, J.A. & Van Breda, L. (1996). Application of a three-dimensional auditory display in a flight task. *Human Factors, 38 (1),* 23-33.

Chiasson, J., McGrath, B. & Rupert, A. (2002). Enhanced Situation Awareness in Sea, Air and Land Environments. *NATO RTO Human Factors and Medicine Meeting Proceedings.*

Dobbins, T. & Samway, S. (2002). The use of tactile navigation cues in high-speed craft operations*. Proceedings of the RINA conference on high speed craft: technology and operation*. (pp. 13-20). London: The Royal Institution of Naval Architects.

Gilliland, K. & Schlegel, R.E. (1994). Tactile stimulation of the human head for information display. *Human Factors, 36 (4),* 700-717.

Hopp, P., Smith, C., Clegg, B., & Heggestad, E. (2005). Interruption management: The use of attention-directing tactile cues. *Human Factors, 47 (1),* 1-11.

McGrath, B.J., Estrada, A., Braithwaite, M.G., Raj, A.K. & Rupert, A.H. (2004). *Tactile Situation Awareness System Flight Demonstration Final Report* (Report 2004-10). Pensacola, USA: Naval Aerospace Medical Research Laboratory.

Mitchell, D., Samms, C., Glumm, M., Krausman, A., Brelsford, M. & Garrett, L. (2004). *Improved Performance Research Integration Tool (IMPRINT) Model Analyses in Support of the Situational Understanding as an Enabler for Unit of Action Maneuver Team Soldiers Science and Technology Objective (STO) in support of Future Combat Systems (FCS).* Aberdeen Proving Ground, MD: U.S. Army Research Laboratory.

Raj, A.K., McGrath B.J., Rochlis, J.L., Newman, D.J. & Rupert, A.H. (1998). The application of tactile cues to enhance situation displays. *Proceedings for the Third Annual Symposium and Exhibition on Situational Awareness in the Tactical Air Environment, 2-3,* 77-84.

Raj, A., Kass, S. & Perry, J. (2000). Vibrotactile displays for improving spatial awareness. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (pp. 181-184). Santa Monica, CA: Human Factors and Ergonomics Society.

Rochlis, J.L. & Newman, D.J. (2000). A Tactile Display for International Space Station (ISS) Extravehicular Activity (EVA). *Aviation, Space, and Environmental Medicine, 71 (6),* 571-578.

Rupert., A.H. (2000). An instrumentation solution for reducing spatial disorientation mishaps. *IEEE Engineering in Medicine and Biology, 19,* 71-80.

Rupert, A.H. (2000). Tactile situation awareness system: Proprioceptive prostheses for sensory deficiencies. *Aviation, Space, and Environmental Medicine, 71 (9),* A92-A99.

Sarter, N.B. (2000). The Need for Multisensory Feedback in Support of Effective Attention Allocation in Highly Dynamic Event-Driven Environments: The Case of Cockpit Automation. *International Journal of Aviation Psychology, 10 (3),* 231-245.

Sarter, N. (2001). Human technology interface: Multimodal communication in support of coordinative functions in human-machine teams. *Journal of Human Performance in Extreme Environments, 5 (2),* 50-54.

Sarter, N. (2002). Multimodal information presentation in support of human-automation communication and coordination. In E. Salas (Ed.), *Advances in Human Performance and Cognitive Engineering Research* (pp. 13-36). New York: JAI Press.

Sklar, A. & Sarter, N.B. (1999). Good vibrations: Tactile feedback in support of attention allocation and human automation coordination in event-driven domains. *Human Factors, 41 (4),* 543-552.

Van Erp, J.B.F. (2002). Guidelines for the use of vibrotactile displays in Human Computer Interaction. In S.A. Wall, B. Riedel, A. Crossan & M.R. McGee (Eds.), *Proceedings of Eurohaptics 2002* (pp. 18-22). University of Edinburgh, Scotland.

Van Erp, J.B.F. (2005). Presenting directions with a vibrotactile torso display. *Ergonomics, 48 (3),* 302–313.

Van Erp, J.B.F. & Van den Dobbelsteen, J.J. (1998). *On the design of tactile displays* (TNO report: 1998 B 012). Soesterberg, NL: TNO Human Factors.

Van Erp, J.B.F. & Vogels, I.M.L.C. (1998). *Vibrotactile perception: a literature review* (TNO report: 1998 B 011). Soesterberg, NL: TNO Human Factors.

Van Erp, J.B.F., Veltman, J.A., Van Veen, H.A.H.C. & Oving, A.B. (2003). Tactile Torso Display as Countermeasure to Reduce Night Vision Goggles Induced Drift. In *Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures. RTO Meeting Proceedings 86,* pp. 49-1 – 49-8. Neuilly-sur-Seine Cedex, France: NATO RTO.

Van Erp, J.B.F. & Van Veen, H.A.H.C. (2003). A multi-purpose tactile vest for astronauts in the international space station. *Proceedings Eurohaptics 2003* July 6th - 9th 2003, Dublin 2 Ireland (TNO report: 2003 P 139). Soesterberg, NL: TNO Human Factors.

Van Erp, J.B.F., Spapé, M.M.A & Van Veen, H.A.H.C. (2003). *Waypoint navigation on land with the TNO Personal Tactile Navigator (PeTaNa) [Waypoint navigatie op het land met de TNO Personal Tactile Navigator (PeTaNa).]* (TNO report: TM-03-A045). Soesterberg, NL: TNO Human Factors.

Van Erp, J.B.F. & Van Veen, H.A.H.C. (2004). Vibrotactile in-vehicle navigation system. *Transportation Research Part F 7* (2004), 247–256.

Van Erp, J.B.F. & Van Veen, H.A.H.C. (2004). Waypoint Navigation on Land: Different Ways of Coding Distance to the Next Waypoint. *Proceedings of EuroHaptics 2004,* Munich Germany, June 5-7, 2004.

Van Erp, J.B.F. & Werkhoven, P.J. (2004). Vibro-tactile and visual asynchronies:Sensitivity and consistency. *Perception, 33,* 103-111.

Van Erp, J.B.F. & Duistermaat, M. (2005). *Tactile guidance for land navigation [Tactiele sturing voor landnavigatie]* (TNO Report: TNO-DV3 2005-C 013). Soesterberg, NL: TNO Defence, Security and Safety.

Van Erp, J.B.F., Van Veen, H.A.H.C., Jansen, C. & Dobbins, T. (2005). Waypoint Navigation with a Vibrotactile Waist Belt. *ACM Transactions on Applied Perceptions, 2 (2),* 1-12.

Van Erp, J.B.F., Ruijsendaal, M. & Van Veen, H.A.H.C. (2005). *A tactile orientation display improves orientation awareness in microgravity: a case study in the ISS* (TNO Report: TNO-DV3 2005 A052). Soesterberg, NL: TNO Defence, Security and Safety.

Wickens, C.D. (1984). *The multiple resources model of human performance: implications for display design.*

Wickens, C.D. (1992). *Engineering psychology and human performance* (2nd ed.). New York: HarperCollins.

Wickens, C.D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3 (2),* 159-177.

Wickens, C.D. & Hollands, J.G. (2000). *Attention, timesharing, and workload. Engineering Psychology and Human Performance.* New York: Prentice Hall.

6 Signature

Soesterberg, December 20, 2005

TNO Defence, Security and Safety,
Location Soesterberg

Drs. J.B.F. van Erp
Project leader

A Training evaluation questionnaire

Land Navigation: Night Operations

TRAINING ASSESSMENT

Roster Number: ___________

Rank ____________ MOS __________ Date ______________________

1. Using the scale below, please circle the appropriate number regarding the training you received.

Very Ineffective	Somewhat Ineffective	Slightly Ineffective	Neutral	Slightly Effective	Somewhat Effective	Very Effective
1	2	3	4	5	6	7

To what extent did the training:

a. <u>Explain</u> the PTN system?	1	2	3	4	5	6	7
b. <u>Provide practice</u> on the PTN system?	1	2	3	4	5	6	7
c. <u>Explain</u> the Land Warrior System (LWS)?	1	2	3	4	5	6	7
d. <u>Provide practice</u> on the LWS?	1	2	3	4	5	6	7
e. <u>Review</u> the PLGR GPS system?	1	2	3	4	5	6	7
f. <u>Provide practice</u> on the PLGR system?	1	2	3	4	5	6	7

Comments:

____

____

____

2. Using the following scale, please circle the appropriate number regarding your experience?

None	Slight	Novice	OK	Good	Very Good	Expert
1	2	3	4	5	6	7

What was your level of experience before training on the:

a. PTN System?	1	2	3	4	5	6	7
b. Land Warrior System?	1	2	3	4	5	6	7
c. PLGR GPS System?	1	2	3	4	5	6	7

3. Using the following scale, please circle the appropriate number regarding the extent to which the instruction helped you understand and explain the:

Very Ineffective	Somewhat Ineffective	Slightly Ineffective	Neutral	Slightly Effective	Somewhat Effective	Very Effective
1	2	3	4	5	6	7

a. PTN System	1	2	3	4	5	6	7
b. Land Warrior System	1	2	3	4	5	6	7
c. PLGR GPS System	1	2	3	4	5	6	7

4. Using the following scale, please rate how well you think you will perform using the:

Very Poorly	Somewhat Poorly	Slightly Poorly	Neutral	Slightly Well	Somewhat Well	Very Well
1	2	3	4	5	6	7

a. PTN System	1	2	3	4	5	6	7
b. Land Warrior System	1	2	3	4	5	6	7
c. PLGR GPS System	1	2	3	4	5	6	7

5. Using the following scale, assume the PTN system works PERFECTLY as explained-- how USEFUL you think would it be for the following?

Very Ineffective	Somewhat Ineffective	Slightly Ineffective	Neutral	Slightly Effective	Somewhat Effective	Very Effective
1	2	3	4	5	6	7

a. Night operations	1	2	3	4	5	6	7	NA
b. MOUT operations	1	2	3	4	5	6	7	NA
c. Reconnaissance	1	2	3	4	5	6	7	NA
d. Sustained Operations (fatigue, etc.)	1	2	3	4	5	6	7	NA
e. Traversing enemy territory	1	2	3	4	5	6	7	NA

6. Using the scale above, assume the Land Warrior system works PERFECTLY as explained-- how USEFUL do you think it would it be for the following?

a. Night operations	1	2	3	4	5	6	7	NA
b. MOUT operations	1	2	3	4	5	6	7	NA
c. Reconnaissance	1	2	3	4	5	6	7	NA
d. Sustained Operations (fatigue, etc.)	1	2	3	4	5	6	7	NA
e. Traversing enemy territory	1	2	3	4	5	6	7	NA

7.Using the scale above, assume the PLGR works PERFECTLY as explained-- how USEFUL do you think it would it be for the following?

a. Night operations	1	2	3	4	5	6	7	NA
b. MOUT operations	1	2	3	4	5	6	7	NA
c. Reconnaissance	1	2	3	4	5	6	7	NA
d. Sustained Operations (fatigue, etc.)	1	2	3	4	5	6	7	NA
e. Traversing enemy territory	1	2	3	4	5	6	7	NA

8. Do you believe you are trained well enough on the following to operate it at night to navigate?

a. PTN: ___ Yes ___No, please explain

---

b. Land Warrior: ___ Yes ___No, please explain

---

c. PLGR: ___ Yes ___No, please explain

---

9. Do you see any safety issues with any of the systems you were trained?
___ Yes ___No, please explain

---

10. What would you do to improve the training of the:

a. PTN?

---

b. Land Warrior?

---

c. PLGR?

---

11. Using the scale below, please rate the systems on relative difficulty of learning each system:

Very Difficult	Difficult	Somewhat Difficult	Neutral	Somewhat Easy	Easy	Very Easy
1	2	3	4	5	6	7

a. PTN Tactile	1	2	3	4	5	6	7
b. LWS Helmet	1	2	3	4	5	6	7
c. PLGR GPS	1	2	3	4	5	6	7

12. Other / Comments (very much appreciated)

B Iteration and route order matrix

Table 1

	ITERATION		
	1	2	3
ROSTER	System / Route no.	System / Route no.	System / Route no.
1	LWS 1	PTN 2	GPS 3
2	PTN 3	GPS 1	LWS 2
3	GPS 2	LWS 3	PTN 1
4	LWS 3	GPS 2	PTN 1
5	PTN 2	LWS 1	GPS 3
6	GPS 1	PTN 3	LWS 2
7	LWS 1	PTN 2	GPS 3
8	PTN 3	GPS 1	LWS 2
9	GPS 2	LWS 3	PTN 1
10	LWS 3	GPS 2	PTN 1
11	PTN 2	LWS 1	GPS 3
12	GPS 1	PTN 3	LWS 2
13	LWS 1	PTN 2	GPS 3
14	PTN 3	GPS 1	LWS 2
15	GPS 2	LWS 3	PTN 1
16	LWS 3	GPS 2	PTN 1
17	PTN 2	LWS 1	GPS 3
18	GPS 1	PTN 3	LWS 2
19	LWS 2	GPS 1	PTN 3
20	PTN 1	LWS 3	GPS 2
21	GPS 3	PTN 2	LWS 1
22	GPS 2	PTN 1	LWS 3
23	LWS 1	GPS 3	PTN 2
24	PTN 3	LWS 2	GPS 1

C Evaluation of navigation device questionnaires

C.1 General questionnaire

Land Navigation: Night Operations
ASSESSMENT OF NAVIGATION DEVICE

Roster Number _______ Date __________________ Time: _________________

Circle Device Used: (PLGR) (Tactile PTN) (Land Warrior HUD)

1. Using the scale below, please rate the device for the following capabilities provided:

Very Ineffective	Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Effective	Very Effective
1	2	3	4	5	6	7

a. Staying on route.	1	2	3	4	5	6	7
b. Rerouting around large terrain obstacles.	1	2	3	4	5	6	7
c. Watching for targets.	1	2	3	4	5	6	7
d. Watching for terrain obstacles (holes, branches, etc).	1	2	3	4	5	6	7
e. Avoiding Off-limits areas.	1	2	3	4	5	6	7
f. Finding waypoints .	1	2	3	4	5	6	7
g. Allowing general situation awareness.	1	2	3	4	5	6	7
h. Allowing hands-free operation.	1	2	3	4	5	6	7

Comments: ____

____

____

2. Using the scale below, please rate the following characteristics of the device:

Very Bad	Bad	Somewhat Bad	Neutral	Somewhat Good	Good	Very Good
1	2	3	4	5	6	7

a. Simple to learn	1	2	3	4	5	6	7
b. Simple to use	1	2	3	4	5	6	7
c. Ease of seeing the display (PLGR and LW only)	1	2	3	4	5	6	7
d. Ease of telling where you are located.	1	2	3	4	5	6	7
e. Ease of staying on the correct route	1	2	3	4	5	6	7
f. Accuracy of the guidance provided by the system.	1	2	3	4	5	6	7

3. What did you like BEST about the system?

____

____

____

4. How would you IMPROVE the system?

____

____

____

5. Using the scale below, assume the system works perfectly (easy, lightweight, hardened, etc), how effective do you think it would be for:

Very Ineffective	Somewhat Ineffective	Slightly Ineffective	Neutral	Slightly Effective	Somewhat Effective	Very Effective
1	2	3	4	5	6	7

a. Night operations	1	2	3	4	5	6	7
b. Day operations	1	2	3	4	5	6	7
c. MOUT operations	1	2	3	4	5	6	7
d. Sustained operations	1	2	3	4	5	6	7
e. Desert Operations	1	2	3	4	5	6	7
f. Wooded Terrain	1	2	3	4	5	6	7
g. Reconnaissance in enemy territory	1	2	3	4	5	6	7

C.2 Additional questionnaire for PTN system

Land Navigation: Night Operations
PTN Tactile Navigation BELT

Roster Number ________________ Date ____________________

1. Using the scale below, please rate the PTN device for the following functions (circle your answer):

EFFECTIVENESS

Very Ineffective	Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Effective	Very Effective
1	2	3	4	5	6	7

a. Easy to tell which tactor is buzzing	1	2	3	4	5	6	7
b. Easy to follow direction	1	2	3	4	5	6	7
c. Easy to tell off-limits area	1	2	3	4	5	6	7
d. Usefulness of "MUTE" button	1	2	3	4	5	6	7

2. Using the following scale, please rate for STRENGTH OF SIGNAL (circle your answer):

Too Weak			Ideal			Too Strong
1	2	3	4	5	6	7

C.3 Additional questionnaire for LWS system

Land Navigation: Night Operations
Land Warrior Helmet-mount Navigation System (LWS)

Roster Number ________________ Date ____________________

1. Using the scale below, please rate the Land Warrior device for the following functions (circle your answer):

EFFECTIVENESS

Very Ineffective	Ineffective	Somewhat Ineffective	Neutral	Somewhat Effective	Effective	Very Effective
1	2	3	4	5	6	7

a. Easy to see map.	1	2	3	4	5	6	7
b. Easy to adjust system (focus, zoom).	1	2	3	4	5	6	7
c. Reliability (need to be restarted, etc.).	1	2	3	4	5	6	7

2. Use following scale for next items (circle your answer):

None	Slight	Some – quite annoying	Quite a bit – would only use if necessary	YES, a great deal— I would not use it
1	2	3	4	5

a. Interference with night vision in other eye	1	2	3	4	5
b. Nausea, disorientation from combination with PVS-14	1	2	3	4	5
c. Screen clutter (too many icons on screen?)	1	2	3	4	5

C.4 End of experiment questionnaire

Land Navigation: Night Operations
END of EXPERIENT QUESTIONNAIRE

Roster Number ________________ Date ____________________

1. Please rank the devices from 1 (best) to 3 (worst) for the following functions

	PTN	PLGR	LWS
Staying on route			
Rerouting around large terrain obstacles			
Watching for targets			
Watching for terrain obstacles (holes, branches, etc.)			
Avoiding off-limits area			
Finding waypoints			

2. Please rank the devices from 1 (best) to 3 (worst) for the following characteristics:

	PTN	PLGR	LWS
Simple to learn			
Simple to use			
Situation awareness allowed			
Ease of telling where you are located			
Ease of staying on the correct route			
Accuracy of the guidance provided by the system			
Best overall system			

3. Comments:

PTN ____

____

Land Warrior ______________________________________

____

PLGR ____

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